TRAFFIC GROOMING IN WDM NETWORKS WITH PATH PROTECTION

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ABSTRACT

For the next generation optical internet to meet the growing traffic needs WDM technology is the key issue to realize high capacity networking infrastructure. In this paper an efficient algorithm is implemented for circuit switching in wide area networks. This algorithm known as semelightpath algorithm has been applied to ARPANET and NSFNET to estimate the blocking probability of a call via fully optical or optoelectronics conversion. Blocking probability has been computed for the above networks. This approach for WDM networks ensures full guaranteed restoration against single link failure on dedicated path protection with and without spare capacity sharing of a network.

KEYWORDS

Lightpath, semilighrpath, wavelength conversion, routing wavelength assignment, ARPANET, NSFNET.

1. INTRODUCTION

Lightpaths provide a powerful approach to tap the vast bandwidth in Wavelength Division Multiplexed networks. A lightpath is an optical path (data channel) established between two nodes in the network and it is created by allocation of the same wavelength throughout the path. It requires no wavelength conversion or electronic processing at intermediate nodes. Therefore lightpaths enable an efficient utilization of the optical bandwidth in WDM networks, thus reducing electronic processing cost at intermediate nodes. It also improves reliability, quality of services, provided to data transmitted through lightpaths.

In general it is not feasible to establish lightpaths between every pair of nodes and to accommodate all the traffic, due to physical constraints such as limited number of wavelengths, tunability of optical transceivers at each node. Given a network, a single optical wavelength may not be available between a given source and destination because some of the resources are already occupied by existing lightpaths. In order to overcome this, we introduce concept of semilightpaths in which a transmission path is obtained by chaining together several lightpaths. Thus, in a semilightpath, wavelength conversion is required at some intermediate nodes, but not at all nodes. The objective of this paper is to present an algorithm for optimally routing semilightpaths between a given source and destination [1]. The figure of merit which we optimize is a combination of the cost associated with a) Traversing a link on some wavelength and b) The cost for wavelength conversion when the path has to switch to different wavelengths at some intermediate nodes.

In the proposed solution, we first transform the network graph into an auxiliary graph, called the wavelength graph (WG), and then find the shortest path in the wavelength graph. The

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shortest path thus obtained corresponds to the optimal semilightpath. In this paper, we show that the shortest path is possible by making use of this special structure of the wavelength graph. We prove that our algorithm is optimal for the cases under consideration in terms of computational time and complexity involved. It provides the best possible lightpaths routing solution. In this paper, we concentrate on the algorithmic issues raised by the optimal routing of the semi light paths [2]. The different network implementation issues of lightpaths have been discussed in papers [6, 7]. In our solution, we assumed that the cost structure is already known from physical considerations and is given as input to the algorithm.

2. PROBLEM FORMULATION

The network topology is modeled by a directed graph G= (V, E), Where V stands for the set of network nodes (vertices in the graph) and E stands for the set of directed links (edges) of the network. Note that the undirected case can be modeled by replacing an undirected edge with two oppositely directed edges.

Assume that a set **$\Lambda = \{\lambda_1 \ldots \lambda_n\}$** of wave lengths is given in the network. The cost structure of using the resources is represented as follows .For each link 'e' and wavelength **λ_i** a weight **$W(e,\lambda_i)$** is representing the "cost" of using wavelength **λ_i** on link 'e'. If **λ_i** is not available on the link, then the weight is infinite. It is assumed that all weights are non-negative.

The cost of wavelength conversion is modeled via cost factors of the form **$C_i(\lambda_p,\lambda_q)$.**This is the cost of wavelength conversion at node 'i' from wavelength **λ_p** to **λ_q** .If for certain values of i,p,q the conversion is not available ,then **$C_i(\lambda_p,\lambda_q)$.**is infinite or a very large number. If the two wavelengths are equal then the cost is zero i.e **$C_i(\lambda_p,\lambda_q)=0$**.The above defined wavelength conversion cost accommodate the general case where conversion cost depend on the nodes and wavelengths involved. In practical networks for example wavelength conversion nodes in critical locations should be used only when necessary, and therefore assigned higher conversion cost. When wavelengths are grouped into wavebands conversion between wavelengths in the same wave band, is less costly than conversion between wavelengths in different wavebands. The conversion cost can also be used to enforce certain rules on how wavelengths should be assigned.

When the traffic is going through a wavelength conversion node is getting closer to the node's capacity, wavelength conversion cost at this node can be increased so that new semilightpaths can be routed through other nodes.

A semilightpath is defined as a sequence **e_i, i=1,..r-**1.Further, a wavelength λ (i) ε Λ is associated with each e_i ,The cost C(P) of a semilightpath P is defined as follows. Let V (e) denotes the endpoint of the link 'e', then cost of 'P' is

$$C(P) = \sum_{i=1}^{r} w[e_i,\lambda(i)] + \sum_{i=1}^{r-1} c_{v(e_i)}[\lambda(i),\lambda(i+1) \quad \text{-----------------------(1)}$$

Here, the first summation gives the cost of traversing the links and the second sum gives the cost of the wavelength conversion at nodes.

In single link failure scenario [5], each lightpath request is computed for active and backup paths. If sufficient bandwidth is not available to set up either the primary or the back-up path, the request is rejected. The assumption here is that both primary and backup paths should not fail together at the same time. The primary and backup paths cannot share a common link for any call in which

A_{ij} = Set of Primary paths that use link (i,j),

B_{ij} = Set of Back-up paths that use link (i,j) ,

F_{ij} = Total Bandwidth reserved by primary path that use link (i,j),

G_{ij}=Total BW reserved by backup paths that use (i,j) link .

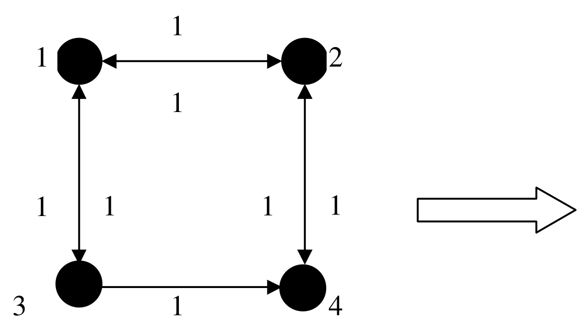
$$F_{ij} = \sum_{k \, \varepsilon \, A_{ij}} b_k \quad \text{-------------------------------------} \quad (2)$$

$$G_{ij} = \sum_{k \, \varepsilon \, B_{ij}} b_k \quad \text{---------------------------------} \quad (3)$$

Here b_k specifies the amount of bandwidth required by request k.The residual bandwidth is defined as $R_{ij} = C_{ij}-F_{ij}-G_{ij}$ of link (i,j), where C_{ij} is link capacity. The objective of the routing algorithm is to determine the primary and backup paths for the current request to “optimize” the use of network infrastructure, so that a minimum amount of bandwidth is used by primary and backup paths.

2.1. Network physical topology design

In a data file, the physical topology of the *network* was given as input. As an example, for a 4-node network shown below, the data file is shown on the right hand side.



2	2	1	3	1
2	1	1	4	1
2	1	1	4	1
1	2	1		

Table 1: Physical topology design example of a 4-node network

In the above network, {1 to 4} denote router nodes. Nodes {1, 2} are connected by a bi-directional link with cost of unity for each unidirectional link. Nodes {3, 4} are connected by a unidirectional link of cost unity.

In the topology matrix, each row (line) corresponds to a router node. Since four nodes are present in the network, four rows are present in the topology matrix. The first column value in each row indicates the number of outgoing links from that router node. Even numbered columns (2^{nd}, 4^{th} .Etc) indicate the router nodes to which the links are connected from that particular router node. Odd numbered columns (3^{rd}, 5^{th} .Etc) columns indicate the costs (weights) associated with the links connecting the particular node to the nodes in even numbered columns (2^{nd}, 4th .Etc) respectively.

As an example, for row 2 i.e. for router 2, two outgoing links are present. Those links are to node 1 (2^{nd} column) and node 4 (4^{th} column). The cost associated with link {2, 1} is unity (3^{rd} column) and cost associated with link {2, 4} is unity (5^{th} column).

4. PROBLEM TRANSFORMATION

In this section we present an efficient algorithm for the problem, the basic idea behind the algorithm is to construct an auxiliary graph, called wavelength graph of the network. The WG is constructed such that a minimum weight path in the WG will correspond to a minimum cost semilightpath.The WG is defined as follows:

1. N=kn vertices, where 'k' is the number of wavelength and 'n' is the number of nodes in the network
2. Arrange the vertices in a matrix-like structure with 'k' rows and 'n' columns. Each column corresponds to a node of the network and each row corresponds to a wavelength. In the i^{th} row ,i=1,…k draw a directed edge from column 'j' to column 'h' whenever there exist a link 'e' form a node 'j' to 'h' in the network and wavelength λ_i is available on the link .Assign the weight w(e, λ_i) to this edge. The subgraph introduced by the i^{th} row of vertices in the wavelength graph is called the λ_i–plane.
3. In column j, j=1...n draw a directed edge from row 'i' to 'l',if at node j wavelength conversion is available from λ_i to λ_l ,assign a the weight C_i (λ_i, λ_l) to this edge. The subgraph induced by the column represents the possible wavelength conversion at node 'i' with their cost.

4. SPAWG ALGORITHM

In this section we present an efficient algorithm for finding shortest path between given vertices of the Wavelength graph.

Step 1 (Initialization)

1. $u_1 = 0;$
2. $if \quad i \sim 1\, then \quad u_i = a_{ij} \;\; else \quad u_i = \infty(\forall i\ )$
3. $R_i = \min\{\ u_i : j\ is\ in\ the\ ith\ row,\ j \neq 1\ \}, (\forall i\ )$
4. $C_j = \min\{u_i : i\ is\ in\ the\ jth\ column\ , i \neq 1\ \}, (\forall j)$
5. $P = \{1\ \}; T = \{2, \cdots, N\ \}.$

Step 2 (Designation of a new permanent label)

1. Find the minimum of $R_i, C_j\, (\forall\, i,\ j\ ).$
2. Find an $h\ \in\ \ T$ with minimum u_h in the row or the column which gave the minimum above (ties are broken arbitrarily)
3. $T = T - \{h\ \}; \quad P = P \cup \{h\ \}$
4. If $T = \phi \quad then\ stop.$

Step 3 (Updating Row and Column minimum)

1. If h, found in step 2, is in row l and column j,
2. $R_i = \min\{u_j : j \quad is\ in\ the\ ith\ row,\ j \varepsilon\, T\ \ \}$
3. $C_j = \min\{u_i : i\ is\ in\ the\ jth\ , i \varepsilon\, T\ \ \},$
4. (The minimum over an empty set is taken to be ∞)

Step 4 (Revision of Tentative labels)

1. If h, found in Step 2, is in row i and column j, then, for all $l \in T$ in the row i, column j set $u_l = \min\{u_l, u_l + a_{hl}\ \}. Go\ to\ step\ 2$

4.1. Results and Discussions

The figures 1, 2 shows that higher the mean arrival rates, higher will be the blocking probability. Thus they are directly proportional to each other the effect of the wavelength conversion on blocking probability was also shown in the figure 1. These results prove the intuitive assumption that the blocking probability with wavelength conversion is less than that without wavelength conversion.

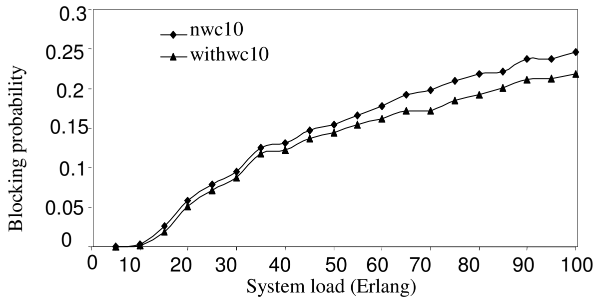


Figure 1. ARPANET with and without 10 WC

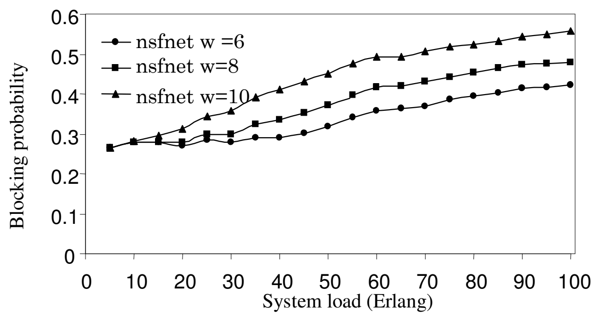


Figure 2. NSFNET with different wavelengths without wavelength conversion

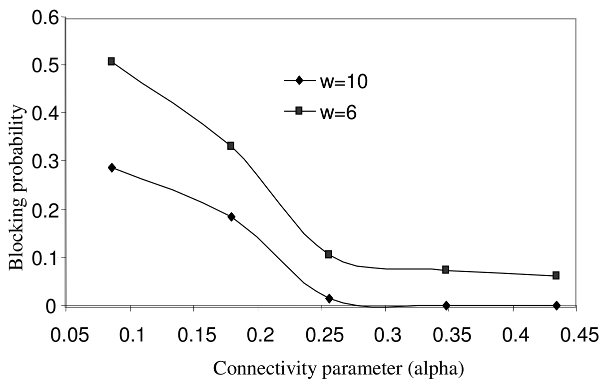


Figure 3. Blocking probability Vs Connectivity parameter

The figures 3 shows that higher the connectivity in the network, lower will be the blocking probability. In addition to this, for particular network connectivity, increases number of wavelengths will decrease the blocking probability.

We have addressed the routing and wavelength assignment strategies for the WDM network. In particular, for the semilightpath model, which provides the basis for simultaneous routing and wavelength assignment using the wavelength path (WP) algorithm. The wavelength path algorithm with λ-conversion is implemented to WDM networks, and has been extended to 24 nodes ARPANET [3] with fixed link as well as dynamic link cost. In the latter case the cost is inversely related to the link availability, and has been found that WP algorithm is quite efficient in terms of computational speed compared to Dijkastra's algorithm to the layered graph model augmented with λ-conversion of a WDM network.

5. SCHEMES FOR NETWORK SURVIVABILITY

In ordered to protect a primary lightpath against single-link failure in an optical network [5] different schemes are available. These schemes are based on two basic survivability paradigms

i) Path protection/restoration and ii) link protection/ restoration.

i) Path protection/restoration

In path protection[8], the source and destination nodes of each connection statically reserves backup paths during call setup. In path restoration, the source and destination nodes of each connection will discover dynamically a backup route in the case of single link failure.

ii) Link protection/ restoration.

In a Link protection/ restoration [8] all the connections that reserve the failed link are rerouted around that link. The source and the destination nodes of the connections traversing in the failed link are oblivious to the link failure. In link protection during call setup, backup paths and wavelength are reserved around each link of the primary path. In link restoration, the end - nodes of the failed link dynamically discover a route around the link, for each wavelength that transverses the link.

5.1. Wavelength assignment in the WDM network with path protection

In the following section we consider path protection strategies as well as wavelength assignment for WDM mesh networks in the case of static and dynamic traffic scenarios.

5.1.1. Static Traffic

a) In path protection without spare capacity sharing (SWOS) for every primary path a link-disjoint backup path is dedicated and it guarantees full restoration.

b) In Path protection with spare capacity sharing (SWS), several protection paths may share their wavelength(s) as long as their corresponding primary paths are link-disjoint, and it guarantees full restoration for single link failure. SWS require less number of protection wavelengths than SWOS.

Case 1: Path protection without spare capacity sharing

1) Find out the shortest-path between (s, d) pair by SPAWG Algorithm

2) Assign wavelength λ_1 to it

3) Remove all links corresponding to the working path from the network

4) Search for the protection path in the reduced network by SPAWG Algorithm for the (s, d) node pair.

5) The protection path is found, continue to assign $\lambda 1$ for protection path cannot be found, and suspend the lightpath search.

6) Repeat the above process for second (s, d) pair. If either the working or path protection cannot be found, suspend the lightpath search.

7) Continue for all (s, d) pairs as above to make full use of $\lambda 1$ assignment

8) Next restore the network to its original topology and proceed to assign λ_2 Wavelength for remaining lightpaths following steps 1-7, above.

9) Continue with W number of wavelengths until all the lightpaths (working and protection) have been accommodated

Case 2: Path protection with spare capacity sharing

The same algorithm can be used with additional features such as spare capacity of $\lambda_{1,}$ and same is assigned to several protection paths.

5.1.2. Dynamic Traffic

In dynamic traffic scenario each lightpath request is computed for primary and backup paths. If sufficient bandwidth is not available to set up path then the request is rejected. The assumption made here is that both primary and backup paths do not fail together at the same time. Sharing of back-up paths reduces the bandwidth consumption. This sharing of backup paths depends on the amount of information available to the Routing algorithm.

i) Dedicated-path protection

In dedicated path protection [8] (also called 1+1 protection), at the time of call setup wavelengths are reserved for each primary, as well as link-disjoint backup paths. The backup wavelength reserved on a particular link of the backup path is not shared with other backup paths. In the following figure first primary path is between A and D via 'B'. And second one is between A and E via 'F'. AD, AE has disjoint backup paths; the backup path of AD is via 'C'. And backup path of AE is via 'B' and 'G'.

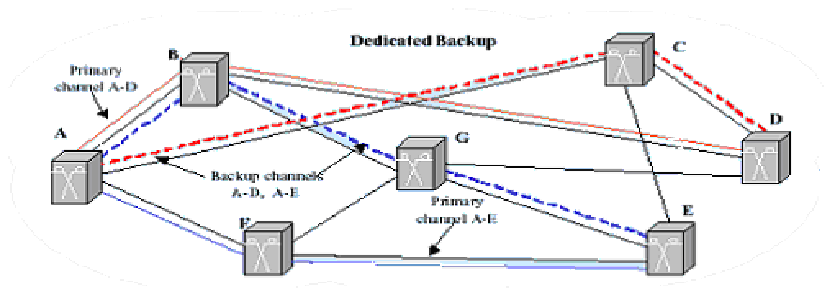


Figure 4.Dedicated path protections

When the information is not shared, the only information available at the time of routing the current request is the residual capacity R for each link (i,j) in the network. Now the current request is for b units of bandwidth between nodes s and d. Since no information is known other than R_{ij}, we have no means of knowing how much backup traffic is being carried by each link and so we have no means to determine how much sharing is possible. Hence, bandwidth of the backup unit b has to be reserved on each link in the primary as well as the backup path. Therefore if, the R< b for link (i,j) then that link then cannot be used of the primary or the backup path for the current request.

The key difference between routing with and without restoration is that we have to determine two link-disjoint paths instead of just determining one path. Since the amount of bandwidth consumed on each link is 'b' units, the objective of minimizing the total amount of bandwidth consumed is equivalent to determining pair of link dis-joint paths. Where the total number of links are minimum. The problem can be formulated as standard network flow problem where each link has unit cost and unit capacity.

The algorithm works as follows:

1: Generate the logical topology for the given physical topology network.

2: Determine the shortest path for the requested call and name that path is primary path.

3: Determine the shortest link disjoint path in the logical topology with respect to primary path and name as backup path.

4: If both, primary and backup paths are available then the call is routed through the computed path otherwise block the requested call.

The performance evaluation of the 14-node with bi-directional link NSFNET network has been carried out using VWP algorithm [4]. The VWP algorithm has been augmented to provide protection against single link failure. The performance of the dedicated path protection strategy with and without failure in the network is envisioned. Finally, the different protection strategies are compared based on the network resource (number of wavelengths) required to meet a predetermined blocking probability for various network loads. The Fig.5 and fig 6 shows the comparison of blocking probability versus total network load for 14-node NSFNET and ARPANET for dedicated path protection with different wavelengths.

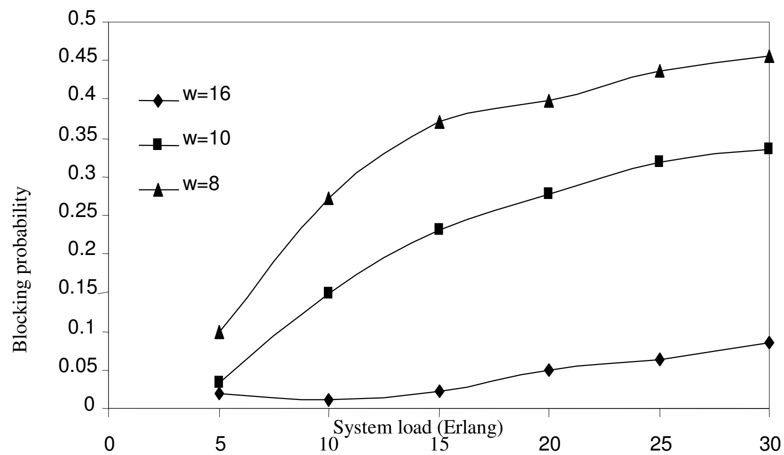


Figure 5.Blocking probability of NSFNET with different lamdas

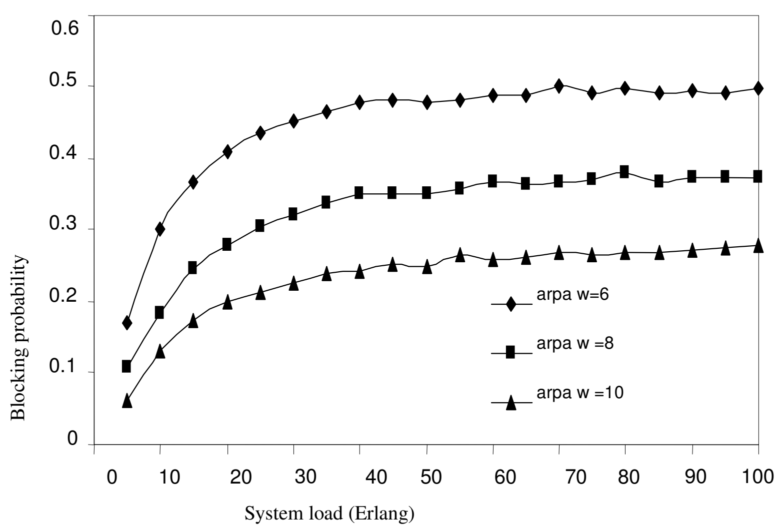


Figure 6.Blocking probability of ARPANET with different lamdas

6. CONCLUSION

An algorithm was presented to optimally solve the problem of fast routing of lightpaths and semilightpaths in wide area optical networks. The obtained lightpath or semilightpath minimizes an overall cost function that accounts both for using the wavelengths on the links and for doing wavelength conversion at nodes when necessary .In addition, we have analyzed simulations on dedicated path protection and their variants for a WDM networks. In particular, we have computed the blocking probability for WDM mesh network with and without link failure. The studies on the performance of WDM networks using wavelength conversion need further investigation to identify the network environment for which the wavelength conversion prove most beneficial. The simplicity and fast running time of the algorithm make it a good candidate for efficient practical implementation. Given the many theoretical as well as practical efforts for constructing optical WDM networks and this result can be readily implemented in the emerging networks.

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